VIABILITY OF BONE CEMENT AUGMENTED COMPRESSION HIP SCREW SYSTEM FOR THE TREATMENT OF INTERTROCHANTERIC FRACTURE: A BIOMECHANICAL ANALYSIS

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Abstract- **Screw cut-out and non-union have been cited as major complications with hip screw systems for the treatment of intertrochanteric femoral fractures. Recently, cement augmentation of hip screw system has been introduced to provide better purchase of the screw. This study investigates the biomechanical efficacy of cement augmentation technique by assessing the changes in stress distributions within the femur and the surgical construct. Finite element models of the operated femur with sliding hip screw assemblies were constructed with and without bone cement augmentation. To simulate the fracture plane and other interfacial regions, 3-D contact elements were used with appropriate friction coefficients. Our results demonstrated the efficacy of the cement augmentation: 80% reduction in stresses was found in the cancellous bone due to cement augmentation, suggesting that the fractures of the cancellous bone and the cut-out of the screw are far less likely to take place. The peak von Mises stress within the cement mantle was about 1/3 of its fatigue strength. The likelihood of cement failure that might lead to osteolysis due to cement debris was not apparent. The micromotion at the hip screw interface was reduced from 0.275mm to 0.008mm, an indication for strong fixation after surgery.**

***Keywords* - Intertrochanteric fractures, Cement-augmentation, Hip screws, Biomechanics, Finite element methods**

I. INTRODUCTION

Recent findings estimate that intertrochanteric femoral fractures (IFF) occur in more than 200,000 patients each year in the United States alone, with reported mortality rates ranging from 15% to 20% [1]. Most intertrochanteric femoral fractures occur in patients over 70 years of age and they are likely to increase each year as the population of these age group increases. In addition, the traumatic patients from traffic accidents make up the ever-increasing patient group. One of the most commonly used surgical treatments for IFF is using internal fixation devices such as sliding compression hip screws with side plate assemblies. These devices are considered to be safe with minimum amount of drilling of the cancellous bone in the femoral head and neck region. They allow early weight-bearing and limit interfacial movement on the fracture plane by providing strong compressive forces.

Clinical studies show, however, that superior cutting-out through the femoral head by the sliding hip screw is one of the major complications [2,3]. Improper screw placement has been cited as one of the major contributing factors. Frequent non-union on the fracture plane often requires revision surgery that can compound more surgical difficulties [2,4]. For patients with severe osteoporosis in which the primary compression trabecular structures have diminished in a great deal can be more prone to this type of complication and add surgical challenges. Strong fixation of the sliding hip screws within the femur and minimum amount of sliding motion must be maintained for the optimal bony-healing.

Biomechanical studies have been done to elucidate the effects of biomechanical factors such as the placement angle of the hip screws, positioning within the femoral head and neck, and the effect of anatomical reduction [5,6]. Recently, augmenting of hip screws with polymethylmethacrylate (PMMA) has been suggested to provide more secure fixation of the screws within the femoral region [3,4]. Clinical study by Cheng et al (1989) found that cement augmentation may provide initial stability but can lead to late complications if not properly used[7]. Bartucci et al (1985) advocated limiting the use of PMMA on the proximal side to prevent intrusion of the cement into the fracture plane[4]. Using cadaveric femurs Choueka et al (1995) investigated biomechanical effects of using various types of sliding hip screws and/or dome plunger in terms of load-bearing and fixation strength [2].

This study was designed to investigate the changes in stress distributions due to cement augmentation. Finite element models of the operated femur with sliding hip screw assemblies were constructed with and without bone cement augmentation. Close attention was given to the peak von Mises stress within the cement mantle region to assess the likelihood of cement failure that might lead to osteolysis due to cement debris. In addition, changes in micromotion at the interfacial junctions such as screw-cement-surrounding cancenllous bone and fracture plane were assessed to study the fixation strength that is critical for post-op bony healing.

II. MATERIALS AND METHODS

A three-dimensional finite element model of the femur was constructed using geometric data acquired from computed tomography (CT) scans (Fig. 1). Intertrochanteric fracture was simulated by assigning a fracture plane from the greater trochanter to the lesser trochanter at 30 degrees with respect to the long axis of the femur (Fig. 2). Based on this hip fracture model, two types of surgical model were generated. One is the non-cemented model (NC) in which only the hip screw assembly was added to the femur and the other is the cement-augmented model (CA) where the cement mantle was added to surround the hip screw (Fig. 3).

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Abstract

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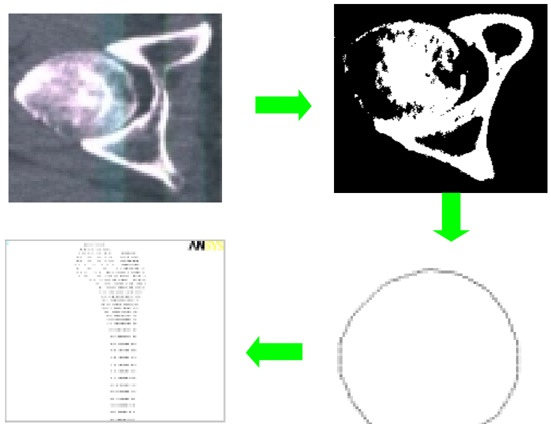


Fig. 1. Geometric data acquired from CT scans

The dimension of the hip screw assembly as well as screw profiles (screw threads, pitches, inner and outer diameters) were based on the Richard compression hip screw (Osteo, Swiss). The distance from the apex of the femoral head to the tip of the screw known as TAD (Tip-Apex Distance) was set at 20-24mm near the center of the femoral head according to suggestion by Baumagaertner ea al [8]. The average thickness of the cement mantle was determined as 12.5mm distributed uniformly over the hip screw based on the clinical experience of one of the authors (SYK).

The material properties for the anatomical and implants were based on the findings from literatures (Table I, [9]). To simulate the interfacial conditions, appropriate friction coefficients (μ) were assigned at the fracture plane (μ=0.5), the interface between screw and surrounding cancellous bone (μ=0.5), and between the screw and the cement (μ=0.3). The cement-bone interface was assumed to be rigidly and the side plate assembly was rigidly fixed to the lateral aspect of the femur. The sources for the friction coefficient are also listed Table I. 2014N of compressive loading in a cubic cosine distribution was simulated on the top of the femoral head at angles of 12 and 26 degrees in sagittal and transverse planes, respectively (Fig. 4). This loading condition is designed to simulate the after heel strike phase in a gait cycle in which the highest compressive load is applied to the femur. It was assumed that the distal part of the model was fixed in all directions. Eight-noded 3-D brick elements were used for the entire model except for the interfacial regions where the 3-D contact elements were used.

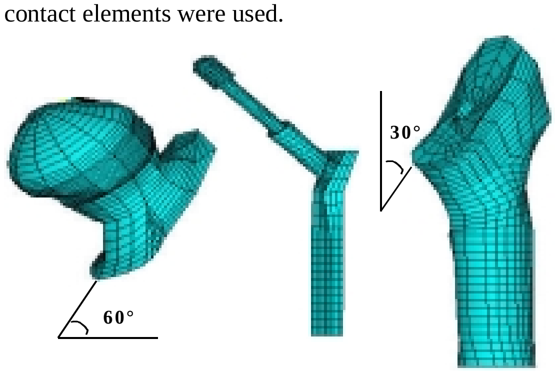
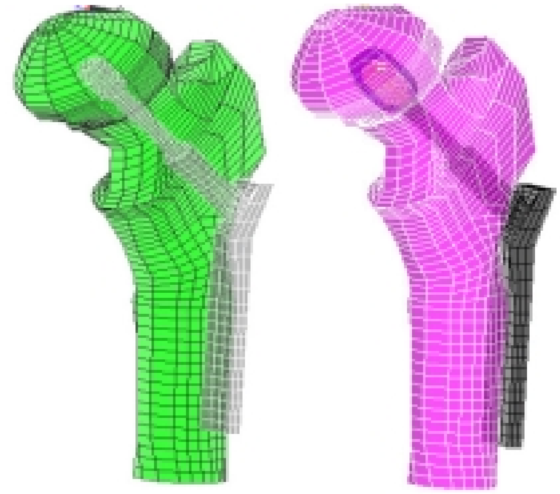


Fig. 2. Construction of a finite element model



(A) (B)

Fig. 3. FE models, (A) non-cemented(NC) (B) cement-augmented(CA)

Total numbers of element and node were 9603 and 11094, respectively. Static and nonlinearity conditions were assumed and ANSYS® v5.7 (Swanson Analysis Corp., USA) was used.

It should be noted that prior to extending the intact model to the surgical model, the intact model was validated by comparing its load-deformation results to those published in a similar loading environment. For this purpose, the strain gage measurement results by Oh et al [10] were used.

III. RESULTS

Strain data from three different locations on the cortical surface of the femur were compared for the validity check (Table II). Here, two sets of results were in a very close agreement with each other, thereby confirming the validity of our model.

Results showed that cement augmentation had resulted in decrease in stresses in the hip screw and in the bone, both cortical and cancellous (Table III), an indication of favorable stress transfer due to the addition of bone cement. Highest decrease in stresses was noted with cement augmentation at the cancellous bone region (reduction of 80%), which makes the further fracture of the femur far less likely in cement-augmented (CA) case than in non-cemented (NC).

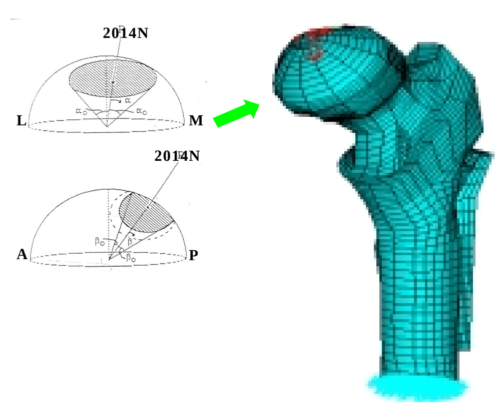


Fig. 4. Loading & boundary conditions of a finite element model

TABLE I.
Mechanical properties of the proximal femur for finite element modeling

		Elastic modulus (MPa)	Possion's ratio (ν)	Coefficient of friction
Cortical bone	Subchondral bone	2,000	0.32	
	Pure cortical bone	14,000	0.32	
Cancellous bone	Femoral head	550	0.32	
	Proximal region	411	0.32	
	Distal region	345	0.32	
Bone cement		2,200	0.23	
Compression hip screw		200,000	0.30	
Cement-screw				0.3 [13]
Cancellous bone – screw				0.5 [14]
Fracture plane				0.5 [15]

In fact, the peak von Mises stresses (PVMS) of 27MPa was aspsessed at the screw-bone junction in the cancellous bone with NC. This exceeded its yield strength of 22MPa suggesting the likelihood of micro-fracture in this region. On the other hand, with CA the corresponding PVMS decreased to 5MPa, making it far less susceptible to fracture. The PVMS at the screw was considerably lower than its yield strength. For example, the PVMS at the hip screw were only 322MPa, slightly above one third of its yield strength of 860MPa (stainless steel). The peak von Mises stress at the cement region was about 9MPa that was far less than 1/3 of its reported shear strength of 30MPa and endurance limit of 28MPa at one million cycles [11].

The micromotions at the screw-bone (NC) and the screw-cement (CA) interfaces were 0.275mm and 0.008mm, respectively. The high level of micromotion in NC coupled with high PVMS that exceeds the yield strength may all contribute the eventual cut-out of the screw because the microscale failure of the cancellous bone and increased micromotion may be initiated.

TABLE II.
Validation results

Location \ Method	Experimental results from Oh et al[8]	Results from the present study using FEM
	Mean ± SD (μ ∊)	
Medial 1	1827 ± 601	1273.6
Medial 2	1419 ± 628	988.4
Lateral	1019 ± 404	623.2
Remarks	Results from strain gauge measurement	Predicted values from matching nodes

TABLE III.
Comparison of peak von Mises stress (PVMS) for the non-cemented (NC) and the cement-augemented (CA) cases

Model location	Non-cemented(NC) PVMS (MPa)	Cement-augmented(CA) PVMS (MPa)	relative %change in PVMS	Yield Strength (MPa)
Hip screw region	322.61	174.97	-45.76	860.00
Cement region		9.16		30.00
Cortical region	48.81	54.63	11.92	560.00
Cancellous region	27.74	4.88	-82.41	22.00

IV. DISCUSSION

This study investigated the biomechanical advantages of adding bone cement to reinforce the hip screw fixation during the surgical treatment of intertrocanteric fracture of the femur by using clinically relevant finite element (FE) models. Although the intertrochanteric fractures often occur in elderly patients with osteoporosis, the material properties of the bone in this study used those of the normal person in order to elucidate its feasibility in a simplified way. It would be very interesting to conduct similar studies for varying degrees of osteoporosis to assess its feasibility by introducing appropriate conversion values for the elastic stiffness in accordance with the BMD data of a given patient.

Our results clearly suggested the biomechanical advantages of bone cement augmentation. In particular, the most drastic reduction in stresses was seen at the cencellous bone. Almost 80% of reduction was noted. This makes the cut-out of the screw that has been advocated as one of the major complications of the hip screw systems far less likely to take place. In fact, the PVMS with non-cemented case was higher than its yield strength (27MPa vs. 22 MPa), a sign of impending loosening of the hip screw at the screw-bone interface that may progress to cut-out of the screw.

No difference in micromotion at the fracture plane was assessed between two cases (CA and NC). At the cement-bone interface, we assumed that interdigitization of cement took place with the irregularities of the bone (i.e., microinterlock). Therefore, we did not assign any friction coefficient. Rather we took it as continuity (i.e., the nodes are shared) and no micromotion was assessed here. It should be noted that at the interface between screw and cement, we adopted the friction coefficient value of 0.3 as suggested by Mann et al [13], which was lower than the that of screw-bone interface (μ = 0.5, suggested by Shrazi-Adl et al [14]). The initial micromotion assessed immediately after surgery has been cited as one of the indicators whether successful bony healing can take place. Studies have shown that micromotion should be less than (0.15mm) for bony fusion at fracture sites [12]. Based on the magnitudes of the micromotion predicted from this study (0.008mm with CA), cement augmentation could reduce the risk of non-union or delayed union of the fracture that might have had progressed otherwise (0.275mm in NC). Our results also demonstrated that despite the lower friction coefficient assigned for the screw-cement interface (CA) its micromotion was substantially less than that of non-cemented (NC). This may due to the fact that the deformation is inversely proportional to the elastic modulus. It appears

higher modulus of bone cement (E= 22000MPa) as opposed to the cancellous bone (E= 550MPa) overcame the relative lack of friction and resulted in less micromotion.

The peak stress found in cement mantle was about less than 1/3 of its fatigue strength. This suggests that the bone cement mantle may theoretically withstand the repeated load indefinitely under the loading condition provided in this study. Although much in-depth study should be done, this result may relieve clinicians from worries about the likelihood of debris-causing fatigue failure that may initiate the vicious cycles of osteolysis and implant loosening.

V. CONCLUSIONS

Biomechanical advantages of cement augmentation in conjunction with hip screw assemblies for the treatment of intertrochanteric fractures of the femur was assessed. They were:

(1) A significant reduction in stresses was seen in the cancellous bone. This is an indication that the additional fractures of the cancellous bone and the cut-out of the screw are far less likely to take place.

(2) Cement mantle could withstand against the physiological load and further against the repeated fatigue load.

(3) The micromotions at the interface were significantly reduced for better bony healing.

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